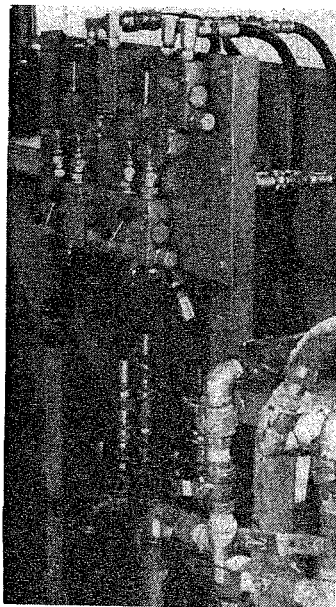


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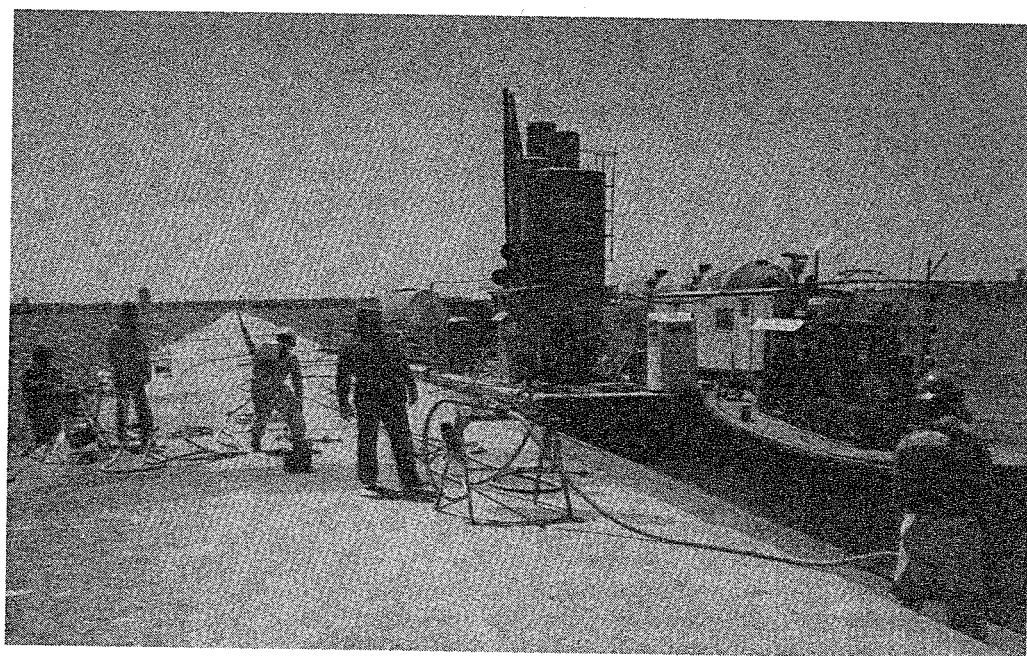
# The REMR Bulletin

News from the Repair, Evaluation, Maintenance,  
and Rehabilitation Research Program

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JUL 1990



Grouting operations at Milwaukee Harbor, Wisconsin, breakwater rehabilitation project

## Underwater – Quick Set and Cement Grouting, An Innovative Method to Rehabilitate Milwaukee Harbor Breakwater

by

Ronald L. Erickson, William A. Ritt and Thomas A. Deja  
US Army Corps of Engineers District, Detroit

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The Milwaukee Harbor, Wisconsin, project, was originally authorized under seven River and Harbor Acts from 1852 to 1962. The function was to provide an outer harbor for commercial vessels, a harbor of refuge and a safe, navigable channel from Lake Michigan to the Kinnickinnic and Milwaukee Rivers. The breakwaters, which were constructed between 1882 and 1899, consisted of a timber cribbing substructure filled with "man- sized" stone. Most of the cribs were founded on crushed stone. Con-

crete superstructures (caps and foot blocks) were added between 1903 and 1909. The caps are 5-ft-thick, mass concrete with minimal reinforcing steel. They rest on 3-ft-thick, precast foot blocks. Steel sheet piling and concrete repairs were performed in the 1950's and early 1960's (Fig. 1).

Partial loss of the stone fill reduced support for the concrete caps, resulting in settlement of the caps, cracking and outward bending of the steel sheet piling, and



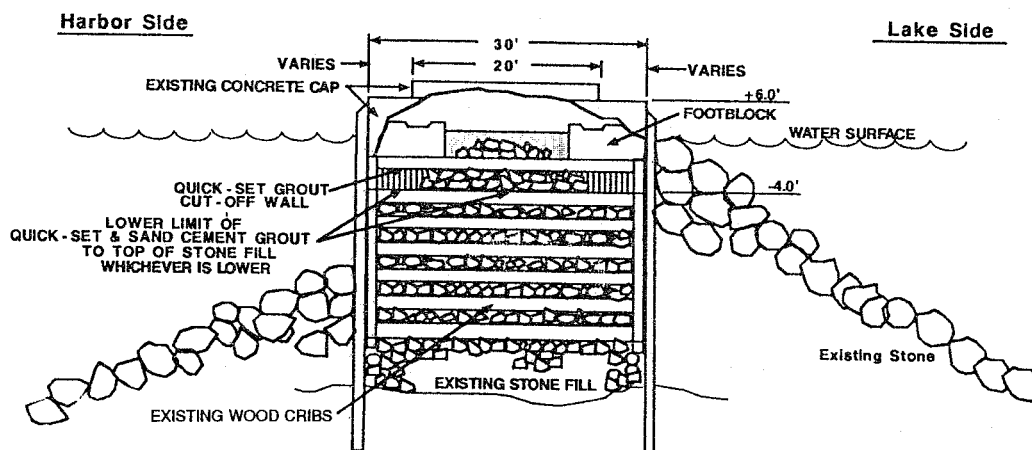


Figure 1. Schematic of a typical section of breakwater at Milwaukee Harbor, Wisconsin

breaking of the tie rods. More of the smaller, interior stone fill, exposed to waves, washed out. To protect the failing steel sheet piling, armor stone was placed along the face of the structure. The structure deteriorated to the point that when waves impacted on the lake side of the breakwater, they would transmit through the structure. It became apparent that the loss of stone fill was progressing at an accelerating rate. A decrease in structure weight resulting from loss of stone fill weight, which resists sliding and overturning, caused the structure to be unstable. Left unchecked, the structure was bound to fail, exposing the harbor features.

### REPAIR METHOD

Several types of repair were evaluated for the rehabilitation of the Milwaukee Breakwater. One method was to remove existing stone protection, drive new steel sheet piling, remove the old caps, and place a new concrete cap. A second method was to demolish the concrete cap and place additional armor stone, converting the structure into a rubble-mound breakwater. Both of these methods would have been very costly due to the length of structure to be repaired and the relatively good condition of the existing caps. In addition, the rubble-mound design would have required large armor stone because of the severe wave exposure and depth of water.

The repair method finally chosen was to grout the interior of the structure. This method would:

- Resupport the concrete cap and prevent future settlement.
- Prohibit additional loss of the stone fill.
- Add weight to the structure to once again make it stable and resistant to overturning and sliding.

### DESIGN NEEDS

The area to be grouted was below water, exposed to open water in numerous places, and subjected to continuous wave surging. Since the grout had to resupport the concrete caps by filling the voids, the grout needed to have the following properties:

- Quick-setting, to prevent water dilution.
- Pumpable through small grout lines.
- Flowable to reach voids in the structure.
- Resistant to freezing and thawing.
- Thick enough to choke off large voids.
- Strong enough to resupport existing concrete caps.
- Inert environmentally.

It was decided to use two separate grouts to meet all of the requirements. Because the faces of the breakwater were exposed, it was deemed necessary to place an exterior wall of sodium-silicate cement grout (quick-set chemical grout) along both sides of the breakwater. Between the two exterior quick-set walls, a sand-cement grout was used as the structural grout to support the concrete caps.

Since the quick-set grout would be the critical factor for success in the project and Detroit District personnel were unfamiliar with the characteristics and properties of quick-set grouting, it was decided to perform laboratory and onsite tests.

A contractor investigated the properties and characteristics of various quick-set grout mixtures and recommended the following:

- A minimum compressive strength of 1,500 psi and a gel time of 2 to 10 sec.
- A relatively low pumping rate to develop the "tremie-type" injection procedure so that the newest grout is never directly exposed to water.
- Quick-set grout holes spaced on 4-ft centers.

To place the grouts below the concrete caps, it was decided to drill holes in the caps and place the grout from the breakwater surface. The grout-hole spacing was a concern. It was necessary to keep the amount of drilling to a minimum to ensure the integrity of the cap. However, the distance the grouts needed to flow was a function of the drill hole spacing (i.e. the thicker the mixture, the closer the hole spacing).

To monitor the flow of sand-cement grout within the structure, an inspection hole was required for every pair of grout holes.

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### MATERIALS USED

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The specifications required the contractor to submit three mixtures for quick-set grout with set times of 10, 15, and 20 seconds. The mixture was to be composed of sodium silicate, cement, fly ash, and water and have a 28-day compressive strength of 1,500 psi.

The quick-set grout used for the project had the following mixture proportions:

#### Cement Solution:

250 lb cement Type I  
50 lb fly ash Type C  
21 gal water

#### Sodium Silicate Solution:

1 part water  
1 part sodium silicate

#### Solution Proportions:

27 gal of cement solution  
9 gal sodium silicate solution

The second type of grout selected was a sand-rich cement grout to be placed between the quick-set grout walls in the interior of the breakwater.

Properties required were water/cementitious material ratio—less than 0.6; sand/cementitious ratio—2:1 to 3:1; fly ash—15 to 40 percent by weight of cement content; compressive strength—3,000 psi minimum; slump—4 to 6 in.

The sand-cement grout selected for the project had the following mixture proportions:

800 lb cement  
200 lb fly ash  
2,500 lb sand  
49 gal water

This mixture provided an average slump of five inches and an average compressive strength of 6,000 psi.

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### CONTRACT

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The contract to grout the Milwaukee Breakwater was awarded July 1987 for \$2.38 million. The contract included drilling grout holes to accomplish the grouting and both quick-set and sand-cement grouting of 3,800 linear feet of breakwater.

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### DEMONSTRATION TESTS

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The first contract requirement was to conduct an onsite capability demonstration. In the demonstration the contractor was required to both quick-set and cement grout a 100-ft long section of the breakwater. The demonstration was conducted to verify that the contractor's methods for drilling, quick-set grouting, and cement grouting would be successful, using the equipment, proportions, and methods proposed. This demonstration also had the objective of testing flow distance versus pressure, properties of mixtures, grouting sequences, and grout hole spacing. The demonstration would be considered successful if the voids between the concrete cap and the top of the stone fill were adequately filled.

Prior to the contractor's moving his equipment to the breakwater for the required capability demonstration, he elected to conduct an onland demonstration of the quick-set grout. This demonstration consisted of quick-set grouting an 8- by 8- by 4-ft covered wooden box filled with water. This demonstration showed that the performance of the quick-set grout was very susceptible to the consistency under which it was injected. The contractor tested several mixture proportions, rates of placement, diameters and lengths of grout tube, and eventually removed an inline static mixer. As a result of these tests, it was found that the grout mixture needed to be a thoroughly mixed, homogenous paste prior to entering the water.

It was also discovered that the point of mixing needed to be retracted farther from the exit point of the grout pipe so that the quick-set grout was extruded as a paste rather than a slurry. This change resulted in the grout flowing in a "lava-like" fashion. After successfully completing the onland demonstration, the contractor moved his operation to the offshore breakwater and performed the required capability demonstration.

The capability demonstration was completed in the fall of 1987, and the results were analyzed during the winter shutdown period. Based on the capability demonstration, the grout hole spacing for the center row of holes was modified, and the required inspection holes were

eliminated. It was also found that the voids under the concrete caps were larger than had been anticipated from the previous subsurface investigations.

## PLACEMENT METHODS

The contractor purchased and mobilized a fully automated, computer operated batch plant. The plant was comprised of a sand bin, cement silo, fly-ash silo, and a heavy duty continuous mixer. The plant was fixed to a barge that was towed daily to the breakwater (Fig. 2).

The same batch plant was used for both the quick-set and the cement grouting. Prior to the start of grouting, the batch plant was calibrated and programmed in accordance with the selected mixture proportions. Intermittently, the plant was checked during the grouting operations to assure that it remained in calibration. All materials batched by the batch plant were automatically recorded on a printout.

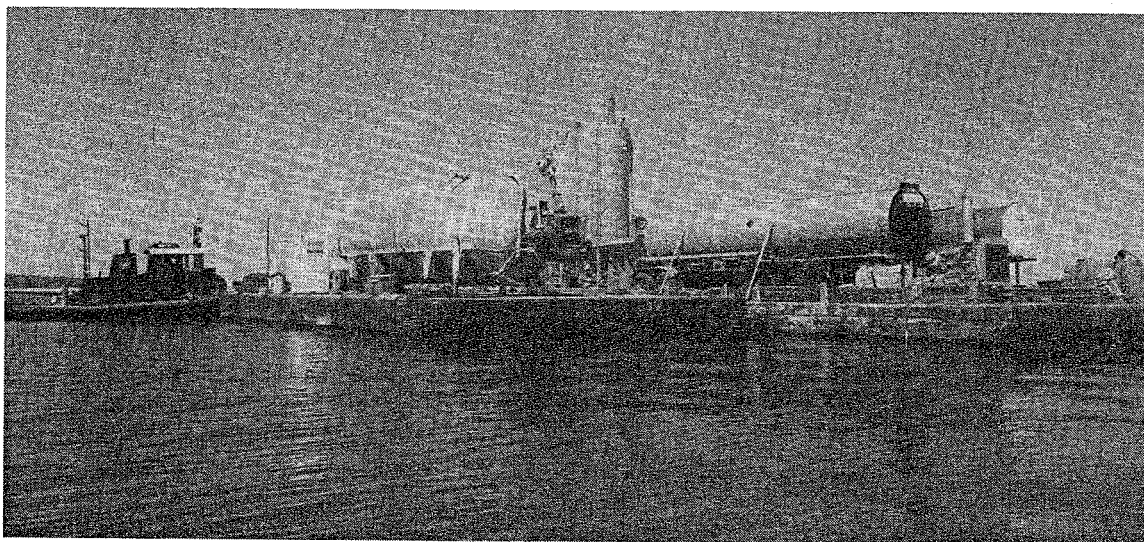
For the quick-set grout, the batch plant dispensed and mixed cement, fly ash, and lake water to comprise the cement component and delivered it into a mechanically agitated holding tank. Sodium-silicate concentrate and lake water were mixed and stored in a separate pressure vessel. The cement component and sodium-silicate solution were pumped independently at rates of 27 and 9 gpm respectively, to the grout header. The two solutions entered the header through a 45-deg "Y" fitting, and continued through 22 ft of flexible 1-in.-diam hose, the last four feet of which were encased in PVC pipe for stiffness. The end of the hose was placed at the bottom of the void and grout injection began. As the grout built up and spread,

the pipe was gradually withdrawn, taking care never to remove the injection point from the previously injected grout. A proper withdrawal rate was very important to assure complete grouting and to avoid sealing the pipe in the grout. The quick-set grout exited the tremie tube in a plastic but flowable state. Two headers were run simultaneously so that grouting could be accomplished on both sides of the structure concurrently.

For cement grouting, the batch plant dispensed and completely mixed the cement, fly ash, sand, and lake water to form the cement grout. Upon leaving the high-speed auger mixer, the grout entered either of two concrete pumps. The sand-cement grout was then pumped through a 2-in.-diam flexible hose to the grout hole. A 2-in.-diam PVC pipe was used at the end of the hose for the grout pipe. The grout pipe was placed with the end of the pipe within 2 in. of the bottom of the hole. A mechanical packer was installed at the top of each hole to seal the annular space between the grout tube and the drilled hole. The PVC pipe was not withdrawn until the adjacent grout hole in the same row of holes was filled. Again, two holes were filled concurrently as a "wave" of grout was pushed laterally through the voids in the structure.

Payment for grouting was based on hundred-weight of cement used in the grout and per cubic yard of grout placed. Quantities of materials delivered, batched, and placed were closely monitored.

Given the delivery tickets, batch-plant printouts, and daily grout-hole records, quality assurance personnel verified that placed quantities were less than/equal to batched quantities which were less than/equal to delivered quantities.



**Figure 2. Tugboat and quick-set grout batch plant mounted on barges shown on location at Milwaukee Harbor.**

Both of the grouts used for the project were tested for compressive strength by molding 3- by 6-in. cylinders. A minimum of four sets of cylinders was required for each 8 hr of grouting operations.

## CONSTRUCTION SEQUENCE

The project involved the following:

First, the quick-set holes were drilled on a 4-ft spacing, three feet in from the face of the structure. These holes were grouted in a "leapfrog" manner, with primary grouting on an 8-ft spacing. Secondary grouting was done on the intermediate holes (Fig. 3).

Then, following the completion of the quick-set grouting, the sand-cement grout was placed in the interior of the breakwater. Lateral movement of the sand-cement grout within the void between the cap and stone was desired, but significant flow down through the stone fill was not desired. The cement grout was pumped in such a way that a "wave front" of grout was continuously moved forward.

A metal pipe was used as a probe to check the flow of grout to the adjacent grout holes. As grout was pumped into one hole, the adjacent hole in the same row was monitored. When the grout filled the hole, the grout pipe was moved to that hole. An important point to make is that the grout tube must remain in the grout at all times, similar to when concrete is tremied underwater, so that the newest grout is not exposed to the water.

## RESULTS

The major problem areas the District anticipated and the methods that were used to prevent the problems from occurring were as follows:

- Assure a thick enough mixture and a compatible hole spacing.

The parameter and ranges of grout mixtures were specified in the contract; the contractor had to submit for approval three distinct mixtures, covering the range of parameters.

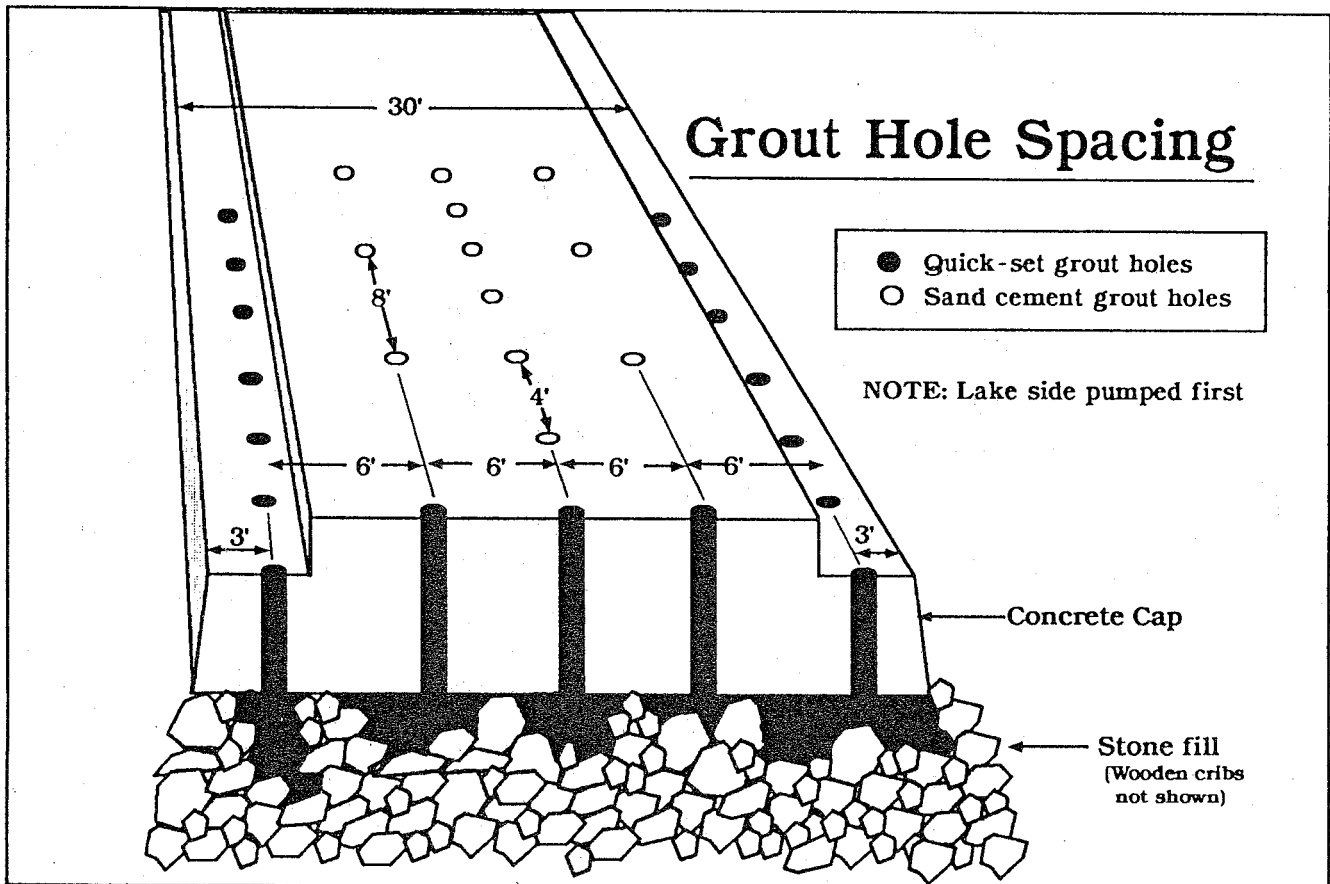


Figure 3. Schematic showing spacing of grout holes for Milwaukee Harbor breakwater rehabilitation.

- Retain grout where it was placed and prevent the grout from flowing beyond required limits.

The specifications limited the pumping rates to allow the grout time to fill voids in the stone fill and the cavities below the concrete cap. A low-slump mixture was required to keep the grout in the vicinity of where it was placed.

- Assure that the grouting would work and the contractor would be able to perform satisfactorily.

The contractor was required to prove his methods in a grout capability demonstration before he was allowed to grout the rest of the structure. The demonstration was completed in a 100-ft portion within the required work area and was paid for at the regular contract unit prices.

- Control the amount of grout pumped into a single grout hole because of unusually large, unexpected voids.

The amount of grout per hole was limited to 8 cu yd per hole.

- Prevent wave surges within the structures from diluting the grouts.

Surges within the crib itself from the wave action of Lake Michigan would dilute the grout. Waves of 3 ft or larger were determined by on-site personnel to be detrimental to the grout. If wave action of 3 ft or higher was encountered, grouting was not permitted.

- Discourage contractors from selecting a cement-rich mixture.

Payment for both cement by the hundred weight used and the cubic yards of grout placed was included in the payment clauses. Also included in the contract were maximum and minimum mixture ranges.

The quick-set grouting and sand-cement grouting of Milwaukee was completed with little difficulty. The major concern was whether the grouts were resupporting the breakwater caps.

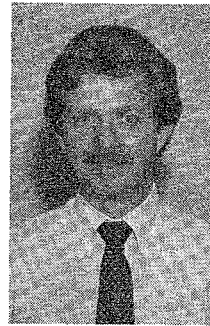
To check the grout after placement, a series of twenty, 4-in.-diam cores was drilled. The cores were taken through the cap and grouts into the underlying stone fill. Inspection of the cores revealed the sand-cement grout was very competent, and, in most cases, the grout was bonded to the bottom of the concrete cap.

One of the cores turned out to be a unique piece. This core encountered a crib timber which happened to contain a knot hole. The knot hole was totally filled with cement grout. Overall the coring indicated that the grouting filled all of the voids between the concrete cap and

the stone fill and sometimes penetrated into the stone fill. Approximately 50 percent of the cores showed the grout penetrating into the stone fill an average of one stone diameter. (The stone was 6 to 18 in. in size.)

The contract for grouting at Milwaukee was completed in August 1988. The final project consisted of drilling 27,873 linear feet of grout holes, placing 2,900 cubic yards of quick-set grout, and 8,250 cubic yards of sand-cement grout.

The Milwaukee breakwater has been subjected to weathering since 1988. Annual inspections and surveys indicate that settlement of the concrete caps has been arrested, and the surging of water into the interior of the structure has been eliminated. Plans are to continue monitoring the structure to determine the long-term benefits of the grouting.



*Ronald L. Erickson is a geologist in the Geotechnical Engineering Section, Design Branch of the Engineering Division at the US Army Engineer District, Detroit. He received a B.S. degree in Geology from Western Michigan University, Kalamazoo, Michigan. In addition to the grouting work for the Milwaukee Harbor projects, he has worked on grouting for foundations, bore holes, and water wells. He has also been involved in various concrete projects.*



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*Thomas A. Deja is a Resident/Project Engineer in the Kewaunee Area Office of the Construction Operations Division, US Army Engineer District, Detroit. In his duties he administers construction contracts involving repairs of piers and breakwaters, and construction of shoreline protection projects. He received his B.S. degree in civil engineering from Michigan Technological University.*

# Lime-Fly Ash Slurry Pressure Injection of Clay Soils for Levee Stabilization

by

*Dennis Abernathy*

*US Army Engineer District, Memphis*

and

*Melton J. Stegall*

*US Army Engineer Division, Lower Mississippi Valley*

In January 1988 a levee slide was reported in the Main Line levee of the Mississippi River near Point Pleasant, Missouri. Point Pleasant, within the "Bootheel" region of the state, is approximately 20 miles north of Caruthersville. The levee at this site is 20 ft high with a 3.5H:1.0V riverside slope and a 5.0H:1.0V landside slope. The 25-ft-wide crown has a 16-ft-wide gravel roadway surface. During the initial site visit, two distinct slides along the riverside slope were identified.

The smaller slide was fully contained within the riverside slope and had the familiar stair-step appearance associated with surficial slides in high-plasticity clays. The larger slide encompassed the entire levee crown width as well as the riverside slope yet did not exhibit the stair-step geometry. For this reason, a detailed geotechnical analysis was performed on that slide to determine the failure mechanism. The analysis confirmed the development of residual shear strengths along the failure plane. This plane was relatively deep and generally paralleled the interface of the levee base with natural ground for that portion beneath the riverside slope. The average plasticity index within the failed mass was 50, and residual strength values varied from  $\phi$  of 12.5 to 14.0 degrees depending on the assumptions made regarding tension cracks and the presence of water.

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## REPAIR METHOD

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After the failure mechanism and controlling soil parameters were identified, several alternatives for stabilizing the slides were considered: slope flattening, berm construction, lime modification, and a technique known as lime-fly ash slurry pressure injection (LFASPI). LFASPI is a patented process developed by the Woodbine Corporation of Dallas, Texas (now the Woodbine Division of GKN Hayward Baker). The Kansas City District used the LFASPI method on a levee test section in 1983. Because of favorable results on this section, the District used the method on the entire levee reach (approximately 2.8 miles) in 1988.

The LFASPI method consists of creating a cementitious mixture of lime and fly ash and injecting it into the soil. The reported advantages of this method over those using lime-only mixtures are the LFASPI's ability to fill large cracks and voids created during movement of the soil mass and its cost effectiveness (the unit cost of fly ash is lower than that of lime).

The construction sequence specified for LFASPI at the Point Pleasant, Missouri, site was as follows:

- (1) Remove and stockpile topsoil and gravel-surfacing.
- (2) Restore levee section, and semicompact work surface to make a smooth and stable platform.
- (3) Make primary injections in swaths perpendicular to the levee centerline, leaving 5-ft spacing between holes and allowing a minimum cure time of 48 hr.
- (4) Repeat Step 2 if movement occurs during primary injections.
- (5) Make secondary injections diagonal to primary holes.
- (6) Disc and semicompact outer 6 in. to incorporate excess slurry into soil.
- (7) Replace topsoil and gravel surfacing.
- (8) Fertilize and overseed levee slope.

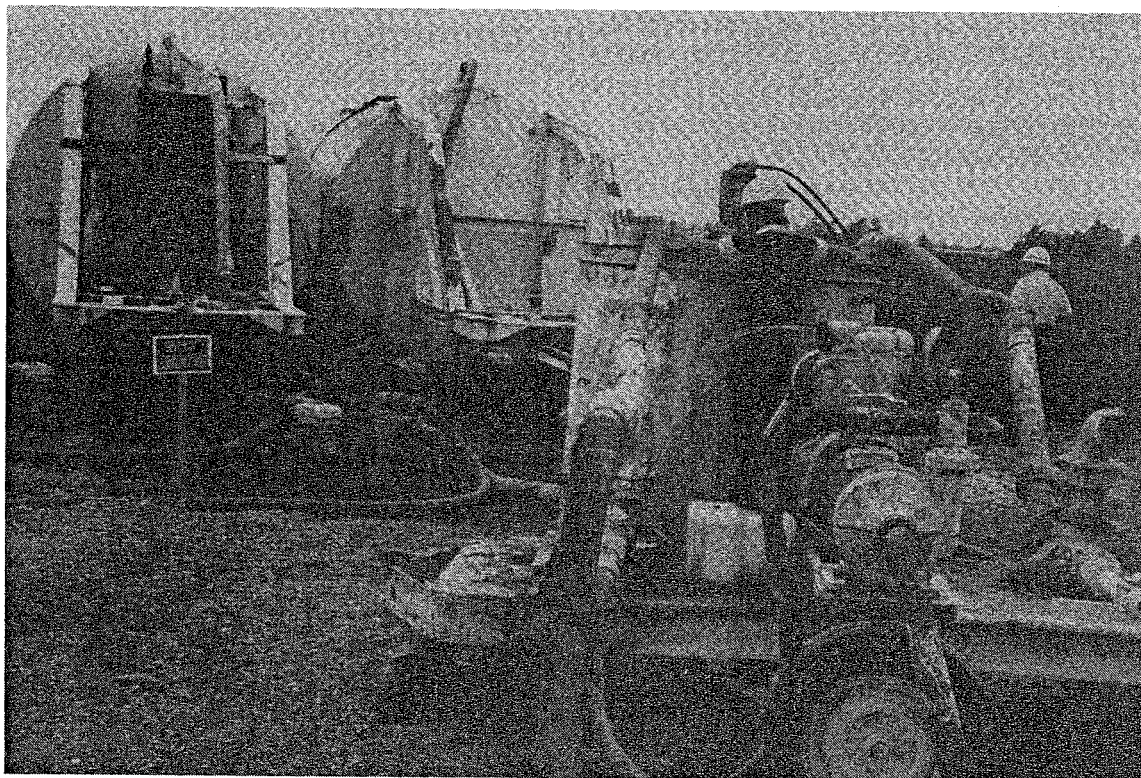
The design slurry mixture consisted of 3 parts fly ash to 1 part hydrated lime (by weight) mixed into a slurry at a rate of 6 to 8 lb per gal of water. The fly ash was Type C, conforming to ASTM C 593. The hydrated lime was in accordance to ASTM C 977. It was obtained by a process patented by the Woodbine Corporation. The process, job-site slaking of calcitic quicklime, results in lower unit costs, finer lime particle sizes, and on-site heat generation. The finer particle sizes improve the qualities of the lime slurry, and heat generation elevates the slurry temperature, thus speeding the chemical reactions.

To obtain the specified slurry, the contractor initially slaked an entire tank load of quicklime, creating a highly concentrated mixture of hydrated lime. When lime slurry was needed, a predetermined amount of this concentrate was transferred to a second tank and diluted with water. This lime slurry was then pumped continuously through a venturi valve and into the adjacent mixing unit (Fig. 1). At the venturi valve, fly ash was blown in from a separate tanker. As part of the quality control program, specific gravity tests were performed every five minutes or whenever there appeared to be any changes in the consistency of the slurry within the mixing tank. When the specific gravity was outside the requirements for the design mixture, the contractor chose to make adjustments to the rate at which fly ash entered the venturi valve. Relay pumps were used to transfer the slurry from the mixing tank to a larger holding tank near the injection site. This tank was of sufficient capacity to prevent the interruption of the slurry supply when the venturi valve clogged or when the concentrated lime slurry was being transferred. A high-pressure pump was used to transfer the slurry from the holding tank to the injection unit. This pump was capable of maintaining a constant pressure of 50 psi and producing an instantaneous pressure of 200 psi at the injection unit. All of the units holding lime or lime-fly ash particles were

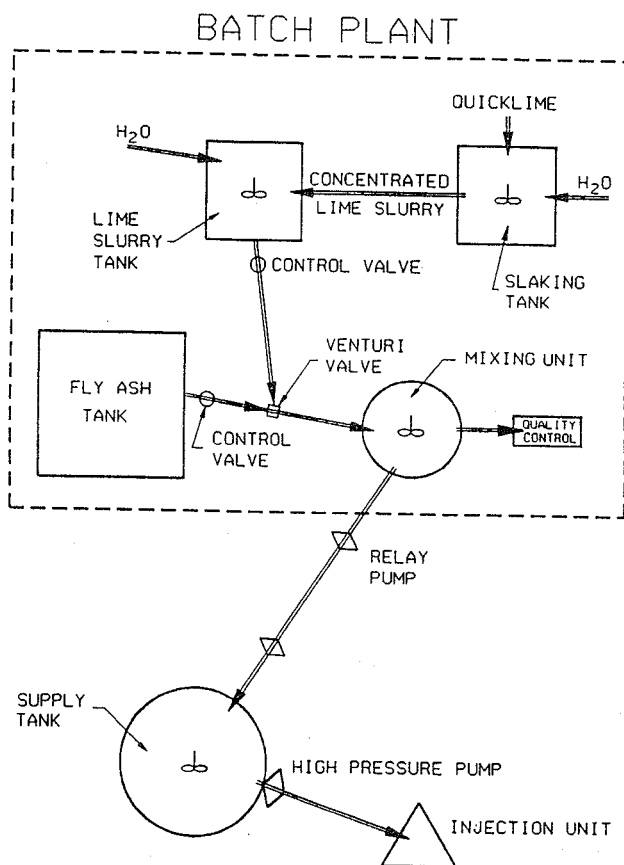
continuously agitated to ensure uniform dispersion of the particles. Figure 2 shows a schematic of the mixing operation.

The injection unit was a small track dozer with three independently operated injection rods attached to the front (Fig. 3). These 1/2-in.-diam rods were spaced 5 ft apart and were capable of penetrating 20 ft. The rods were pushed into the soil in 12- to 18-in. increments, and the slurry was injected at each interval until refusal was achieved. Refusal was defined as the point at which slurry ran freely from previous injection holes or from ground cracks or there was excessive blowback around the injection rods. A decision was made to increase the injection intervals to 18 to 24 in. This change reduced the amount of blowbacks and increased the amount of ground take. Other than this modification, the injection was performed according to specifications. Upon completion of the slurry injection, the remaining items of levee restoration were performed without incident.

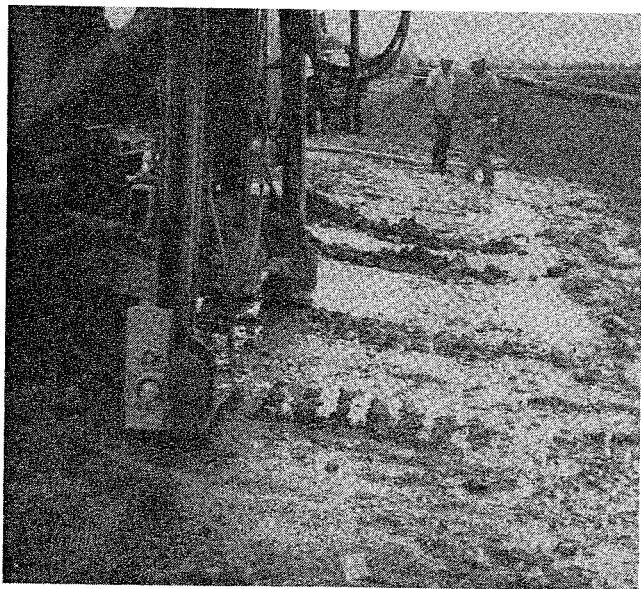
The cost of the LFASPI stabilization was approximately \$3.10 per cu yd, based on treating 27,000 cu yd of material. This cost represents only injection costs; it does not include any cost for levee reshaping or turfing.



**Figure 1. Materials tanks, mixing unit, and relay pumps for lime-fly ash slurry pressure injection**



**Figure 2. Schematic showing batch plant for lime-fly ash slurry**

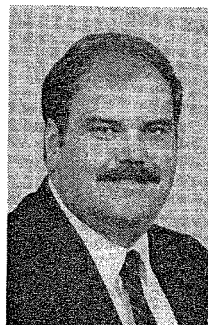


**Figure 3. Injection unit for lime-fly ash slurry is attached to bulldozer**

## CONCLUSIONS

The effectiveness of LFASPI in slope repair on this project may not be known for several years. However, since this method was selected, in part, due to the typical and extreme conditions that existed (shallow and deep failure planes) slope inclinometers have been installed to evaluate the effectiveness. It is reported, informally, that the Kansas City District project has shown some longitudinal cracking but has experienced no additional sliding since the October 1988 completion.

For further information, contact Dennis Abernathy at (901) 544-3381 or Melton Stegall at (601) 634-5900.



*Dennis Abernathy, a registered professional engineer, has been employed as a geotechnical engineer with the Memphis District since 1982. He works within the Geotechnical Design Section where he serves as a project engineer overseeing the design and repair of various flood control structures. He received his B.S. and M.S. degrees from Memphis State University.*



*Melton (Mel) J. Stegall is a division materials engineer with the US Army Corps of Engineers, Lower Mississippi Valley Division, Vicksburg, MS. He received his B.S. and M.S. degrees from Mississippi State University. He is a member of the American Concrete Institute.*

## **Next Phase of REMR Research Program to Start up in October 1990**

With a first-year budget of \$4 million, the REMR Research Program enters into its second phase. A program outline for several years will be on the table when the Field Review Group meets in late August to prioritize research studies.

The follow-on program was approved based upon the success of the initial effort. The REMR program clearly demonstrated the benefits that can be derived from this type of research. More than \$68 million in savings accumulated during the duration of REMR's first 6 years, and additional savings and benefits accrue each time the new technology is applied. Estimated savings over the next 5 years will exceed \$200 million for the Corps alone.

REMR-II will concentrate on problems and areas which have the potential for large payoffs and widespread

applications. Much of the technology that will be produced will have application outside the Corps to other types of infrastructures. A significant effort will be devoted to the coordination and sharing of this technology with other federal agencies, state and local governments, and the private sector.

The continued safe and efficient operation and maintenance of Corps projects is essential to the economic well-being of the country. The cost associated with the evaluation, maintenance, repair, and rehabilitation of Corps of Engineers projects have become a major part of the Corps' budget. The REMR-II Research Program will help to ensure that the Corps gets the maximum value for the dollars expended.

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# COVER PHOTOS:

Hydraulic controls for monitoring quick-set grouting at Milwaukee Harbor, Wisconsin, breakwater rehabilitation project

Materials tanks and relay pumps for lime-fly ash slurry pressure injection



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